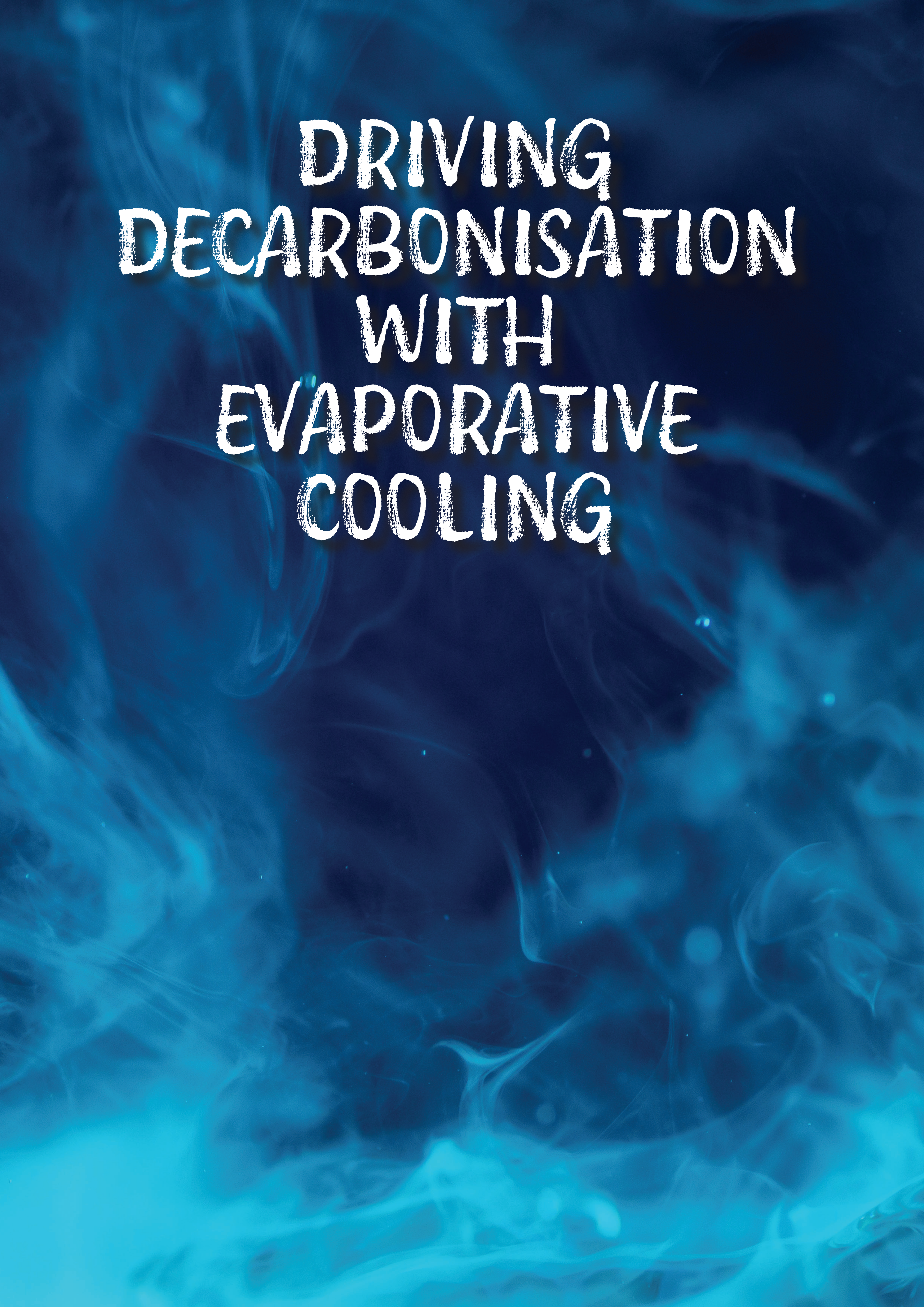


DRIVING DECARBONISATION WITH EVAPORATIVE COOLING

Ashwin Patni, Lechler USA, explores how evaporative cooling and CFD-driven design can optimise clinker cooler performance while reducing energy use and emissions.

As cement producers face unprecedented pressure to decarbonise, the clinker cooler is emerging as a hidden lever in the industry's energy and emissions profile. With fuel costs rising and carbon intensity under scrutiny, every percentage of heat recovered or kWh saved makes a measurable difference. One area often overlooked is the impact of the cooler's exhaust management on the induced draft (ID) fan. Because the ID fan must handle the full exhaust stream, any inefficiency in cooling strategy translates directly into higher fan power draw, operating cost, and ultimately, higher CO_2 emissions from the plant's electrical load.

At its core, the clinker cooler serves two essential functions: it rapidly cools clinker discharged from the kiln, and it recuperates heat for reuse in the pyroprocess. The cooler's hot zone directs high-temperature secondary and tertiary air back into the kiln and calciner, dramatically reducing fuel demand and stabilising process chemistry. But once that usable heat is extracted, the downstream cooling zone determines how efficiently exhaust gases are conditioned before entering dust collection and the ID fan system. Here, the cooling method becomes not just a technical choice but a strategic one.

This challenge is magnified as producers push for greater throughput through higher kiln feed rates. With more material moving across the cooler, exhaust temperatures tend to rise over time, which in turn increases the volumetric flow rate handled by the ID fan. The result is often a maxed-out fan, unable to provide sufficient draft. Worse, this condition reduces the pressure available for cooler fans to blow air through the clinker bed – leading to process constraints, uneven cooling, and ultimately, suboptimal kiln and cooler performance.

To manage downstream exhaust, cement plants typically choose between three approaches: evaporative spray cooling, air-to-air heat exchangers, or dilution air. Among these, evaporative cooling has proven the most cost-effective both in capital expenditure and operation. Spray systems are compact, flexible, and relatively low in maintenance, making them attractive for plants balancing tight budgets with decarbonisation commitments.

Air-to-air heat exchangers, on the other hand, cool the exhaust by rejecting heat directly to the atmosphere. They are very large, capital-intensive, and require regular maintenance, which often limits their adoption. However, they have a distinct benefit: because no water vapour is added, the cooled gases retain a lower volumetric flow compared to evaporative systems – helping to ease the burden on the ID fan. On the downside, they are not very quick to respond to large upset conditions.

Finally, dilution air systems are the simplest, but they add significant volumes of ambient air, increasing fan power demand and filtration costs while forfeiting energy recovery.

In this context, evaporative cooling still represents the practical middle ground. By lowering exhaust temperatures efficiently and with minimal footprint, it protects downstream filters, optimises ID fan performance, and avoids unnecessary power penalties – all while enabling plants to sustain clinker throughput without compromising clinker quality.

Why gas cooling?

Gas cooling in the clinker cooler exhaust is not simply an auxiliary step; it is central to both plant reliability and pyroprocess stability. After the hot recuperation zone has supplied secondary and tertiary air, the remaining exhaust stream still exits at elevated temperatures – typically in the range of 250 – 400°C depending on kiln feed rate, cooler design, and operating conditions. Without proper cooling, this stream cannot be directed to downstream equipment such as bag filters, electrostatic precipitators, or ID fans. The need for gas cooling is driven by four key factors:

Equipment protection
High gas temperatures can shorten the life of filter bags, damage ductwork linings, and reduce fan availability. Cooling ensures that all downstream equipment operates within design limits.

ID fan performance

Exhaust temperature has a direct impact on gas density. Hotter gas expands, increasing the volumetric flow rate that the ID fan must handle. If temperatures rise unchecked, the ID fan may max out, restricting the draft available to the cooler fans. This reduces airflow through the clinker bed, undermining cooling efficiency. This scenario is also a major driver of dust emissions near the clinker cooler.

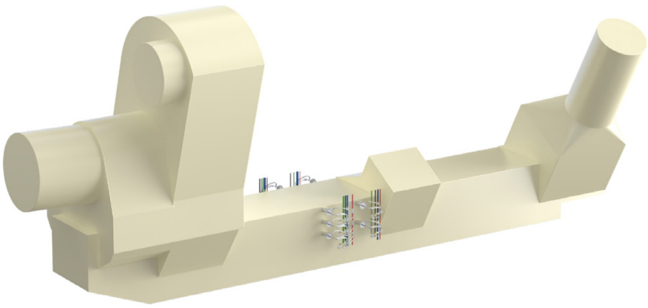


Figure 1. Clinker cooler design with water sprays.

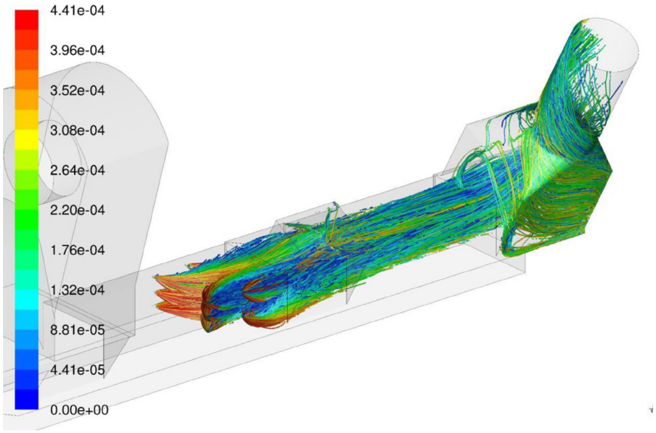
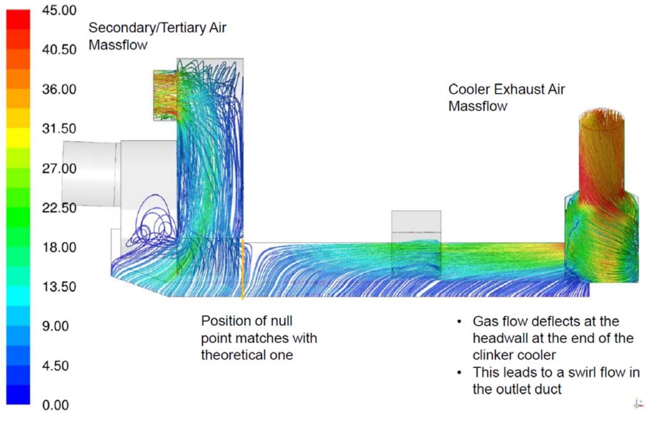


Figure 2. A CFD model for a spray nozzle.



Position of null point matches with theoretical one

- Gas flow deflects at the headwall at the end of the clinker cooler
- This leads to a swirl flow in the outlet duct

Figure 3. Null point location and gas distribution modelling.

Process stability and null point control
The null point – the line within the clinker bed where the downward flow of clinker balances the upward flow of cooling air – is a critical operating parameter. Proper gas cooling helps maintain system pressure balance so that the null point remains in the optimal location. If exhaust gases are too hot and fan draft is compromised, the null point can shift unpredictably. This leads to uneven clinker cooling, elevated clinker outlet temperatures, and reduced recuperation efficiency in the hot zone.

Environmental compliance
Gas cooling ensures stable operation of dust collection equipment, maintaining emissions within permitted levels and avoiding costly non-compliance events.

In practice, the method of gas cooling – whether via evaporative sprays, air-to-air heat exchangers, or dilution air – has a direct bearing on fan load, clinker cooling uniformity, and overall thermal efficiency. Beyond simply lowering exhaust temperatures, an optimised cooling system ensures the clinker cooler operates at its design null point, stabilising the entire kiln line and enabling higher throughput under the current twin pressures of energy cost control and decarbonisation.

Evaporative gas cooling system

Among the available options, evaporative gas cooling remains an attractive low capital cost method for conditioning clinker cooler exhaust. By injecting finely atomised water sprays directly into the hot gas stream, the system removes heat primarily through latent heat of evaporation, bringing the gas down to a safe and controlled temperature before it enters the baghouse and ID fan. Two atomisation technologies dominate cement industry practice: twinfluid systems and spillback systems.

Twinfluid system

In a twinfluid system, compressed air (or sometimes steam) is used in combination with water to produce very fine droplets. The small droplet size ensures rapid evaporation, highly efficient cooling, and tight temperature control. Typical benefits include:

- Very fine droplet spectrum – complete evaporation and uniform cooling.
- Ideal for systems where residence time is very short.
- Precise response to load fluctuations, ideal for plants with variable throughput and managing upset conditions.
- Suitable for high-temperature, high-load applications.

Spillback system

A spillback system uses only water, with internal hydraulic recirculation to generate atomisation. A portion of the water is returned to the tank while the rest is sprayed into the gas stream. This eliminates the need for compressed air. Typical benefits include:

- Lower operating cost (no compressed air system required).
- Mechanically simpler, with fewer auxiliary components.
- Attractive where water is very hard.

Both systems, when properly designed, are capable of ensuring complete evaporation and precise gas temperature control. The choice often depends on local priorities: twinfluid for maximum control and fineness of atomisation, spillback for lower CAPEX/OPEX and simplicity.

The role of CFD in evaporative cooling

The performance of an evaporative cooling system is not determined by nozzle design alone – it depends on how sprays interact with the hot gas stream. This is where computational fluid dynamics (CFD) has become indispensable.

- Droplet size vs. residence time. For complete evaporation, the droplet size must be matched to the available residence time in the duct. CFD helps predict gas velocities, turbulence, and trajectories, ensuring that spray patterns and droplet spectra are optimised for full evaporation within the available space.
- Spray orientation and wall impingement. Incorrect lance placement or orientation can cause droplets to hit duct walls or even reach the baghouse partially evaporated. CFD allows engineers to model droplet trajectories and adjust lance angles, ensuring sprays remain fully suspended in the gas stream and do not cause mud formation.
- Defining the null point and flow fields. In the clinker cooler, CFD helps identify the null point where gas and clinker flows balance, and maps velocity profiles in the exhaust duct. This ensures that sprays are introduced in regions of stable flow where evaporation is maximised.
- Reliable operations. By aligning droplet size, spray orientation, and gas dynamics, CFD transforms evaporative cooling from a low-cost solution into a high-reliability process that protects filter bags, stabilises temperatures, and minimises maintenance disruptions.

Volumetric change, baghouse sizing, and fan energy implications

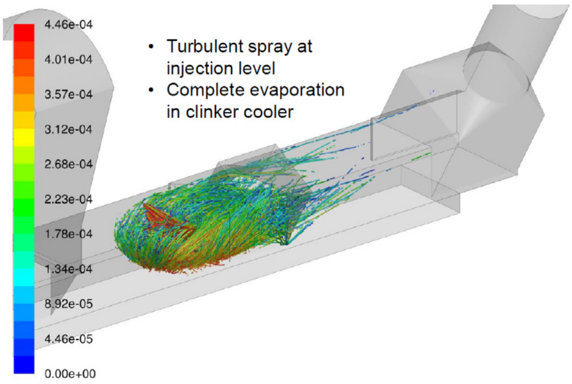


Figure 4. Complete water evaporation.

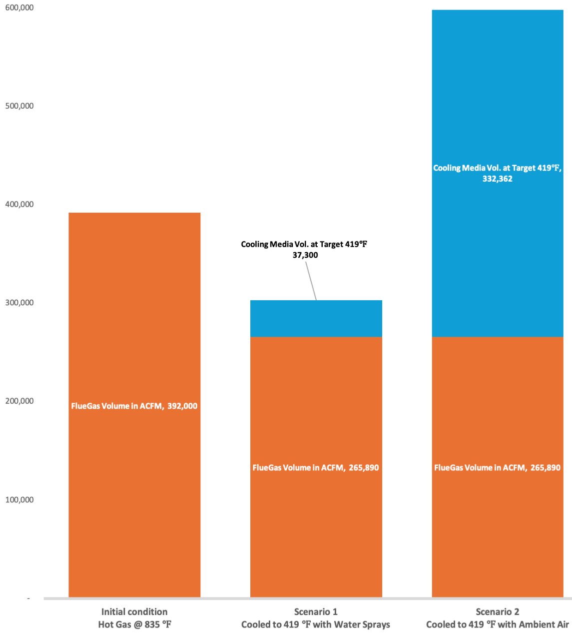


Figure 5. Water spray vs. tempering air cooling.

One of the most consequential choices in hot gas conditioning is whether to reduce temperature by evaporative water cooling or by dilution with ambient tempering air.

While both strategies can achieve the same target outlet temperature, their impact on downstream equipment sizing and operating costs diverges sharply. A key differentiator is the volumetric flowrate of the gas after cooling, which directly drives the size of the baghouse and the energy required from the ID fan. The following is a case study for a cooler in Europe.

Process conditions

- Clinker cooler exhaust flue gas: 392 000 ACFM.
- Inlet gas: 835˚F.
- Target outlet at the Baghouse: 419˚F.
- Ambient air: 86˚F.

Case A: evaporative water cooling

Water at 86˚F is sprayed and fully evaporated (≈125 gpm).

- Outlet flow: 303 000 ACFM.
- Baghouse area (A/C = 6 ft/min): 50 500 ft^2.
- ID fan load (20 in. w.g., 65% eff.): 1470 hp.

The key takeaway is that water injection reduces outlet gas volume, which lowers fan power demand and baghouse size.

Case B: tempering air cooling

Cool air at 8˚F is added (≈250 lb/s).

- Outlet flow: 598 000 ACFM.
- Baghouse area (A/C = 6 ft/min): 99 700 ft^2.
- ID fan load (20 in.w.g., 65% eff.): 2900 hp.

The design avoids the use of a water system, but nearly doubles the volume and baghouse size, with ~2× higher fan energy.

Comparison

- Volume comparison: 303 000 vs. 598 000 ACFM – tempering air almost doubles flow.
- Baghouse: 50 000 vs. 100 000 ft^2 – nearly 2× filter area.
- Fan power: 1470 vs. 2900 hp – ~2× increase in required energy on the system curve.

The comparison highlights a fundamental trade-off. Tempering air avoids water-handling equipment and associated risks of droplet carryover, corrosion, or dew point limitations, but it does so at the cost of very high fan horsepower and a significantly larger baghouse footprint. Evaporative cooling, by contrast, minimises volumetric load and reduces the size and operating cost of the downstream gas-handling train, though it requires careful nozzle selection, atomisation energy, and process control to ensure complete evaporation.

Ultimately, the choice has less to do with the ability to meet the cooling target – both achieve 215˚C – and more to do with lifecycle economics: higher capital and operating costs for the air route vs. lower fan and baghouse costs, but added water system complexity, for the evaporative route. Lechler has many retrofitted water spray cooling systems which have proven performance, and now, with the aid of CFD, water gas cooling system are even more reliable.

Key takeaways

The following key takeaways highlight the performance advantages and strategic benefits of modern evaporative gas cooling systems, particularly when supported by CFD and advanced atomisation technologies:

- Modern clinker coolers and gas cooling systems have evolved into reliable, low-cost solutions that directly support process and decarbonisation goals.
- CFD modelling upfront enables accurate definition of the null point, correct lance positioning, and alignment of droplet size with available residence time – ensuring complete evaporation and stable operation.
- Together, CFD-driven design and advanced atomisation technology make clinker cooler gas conditioning a predictable, efficient, and future-ready process, supporting higher throughput while safeguarding efficiency and emissions compliance. ■

About the author

Ashwin Patni is the Director of the Process Technology Division at Lechler Inc., where he leads commercial and technical strategy for advanced spray-based process systems across the cement, lime, power, and chemical industries. A chemical engineer with an MBA from Northwestern University's Kellogg School of Management, Ashwin brings over 15 years of experience in mass-transfer and air-pollution-control applications, including gas cooling systems, SNCR/DeNOx, and WFGD scrubbing technologies.